

## **Do not turn the pages of the exam until you are instructed to do so.**

**Exam rules:** You may use **only** a writing instrument while taking this test. You may **not** consult any calculators, computers, books, nor each other.

Problems 1 and 10 must be answered on the scantron form. Problems 11 and 12 must be answered in exam booklet 1. Problem 13 must be answered in exam booklet 2. The answers need to be well motivated and expressed in terms of the variables used in the problem. You will receive partial credit where appropriate, but only when we can read your solution. Answers that are not motivated will not receive any credit, even if correct.

At the end of the exam, you must hand in your exam, the scantron form, the blue exam booklets, and the equation sheet. All items must be clearly labeled with your name, your student ID number, and the day/time of your recitation. **If any of these items are missing, we will not grade your exam, and you will receive a score of 0 points.**

**You are required to complete the following *Honor Pledge for Exams*. Copy and sign the pledge before starting your exam.**

"I affirm that I will not give or receive any unauthorized help on this exam, and that all work will be my own."

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$$\cos(30^\circ) = \frac{1}{2}\sqrt{3} \quad \sin(30^\circ) = \frac{1}{2} \quad \tan(30^\circ) = \frac{1}{3}\sqrt{3}$$

$$\cos(45^\circ) = \frac{1}{2}\sqrt{2} \quad \sin(45^\circ) = \frac{1}{2}\sqrt{2} \quad \tan(45^\circ) = 1$$

$$\cos(60^\circ) = \frac{1}{2} \quad \sin(60^\circ) = \frac{1}{2}\sqrt{3} \quad \tan(60^\circ) = \sqrt{3}$$

$$\cos\left(\frac{1}{2}\pi - \theta\right) = \sin(\theta) \quad \sin\left(\frac{1}{2}\pi - \theta\right) = \cos(\theta)$$

$$\cos(2\theta) = 1 - 2\sin^2(\theta) \quad \sin(2\theta) = 2\sin(\theta)\cos(\theta)$$

Circle   Sphere

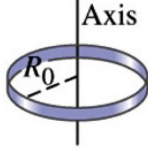
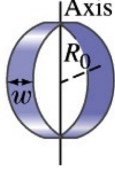
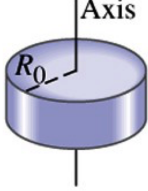
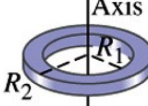
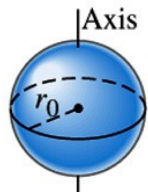
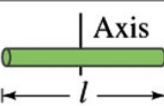
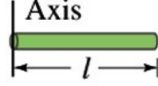
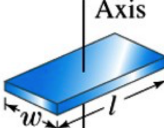
circumference    $2\pi r$

(surface) area    $\pi r^2$     $4\pi r^2$

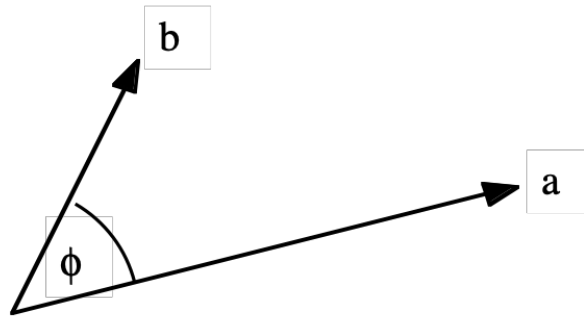
volume    $\frac{4}{3}\pi r^3$

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## Moments of inertia of various objects of uniform composition.

(a)	Thin hoop of radius $R_0$	Through center		$MR_0^2$
(b)	Thin hoop of radius $R_0$ and width $w$	Through central diameter		$\frac{1}{2}MR_0^2 + \frac{1}{12}Mw^2$
(c)	Solid cylinder of radius $R_0$	Through center		$\frac{1}{2}MR_0^2$
(d)	Hollow cylinder of inner radius $R_1$ and outer radius $R_2$	Through center		$\frac{1}{2}M(R_1^2 + R_2^2)$
(e)	Uniform sphere of radius $r_0$	Through center		$\frac{2}{5}Mr_0^2$
(f)	Long uniform rod of length $l$	Through center		$\frac{1}{12}Ml^2$
(g)	Long uniform rod of length $l$	Through end		$\frac{1}{3}Ml^2$
(h)	Rectangular thin plate, of length $l$ and width $w$	Through center		$\frac{1}{12}M(l^2 + w^2)$

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**Properties of the scalar product**

$$\vec{a} \bullet \vec{b} = |\vec{a}| |\vec{b}| \cos \phi \quad (1)$$

$$\vec{a} \bullet \vec{a} = |\vec{a}|^2 \quad (2)$$

$$(\vec{a} + \vec{b}) \bullet (\vec{a} + \vec{b}) = \vec{a} \bullet \vec{a} + \vec{a} \bullet \vec{b} + \vec{b} \bullet \vec{a} + \vec{b} \bullet \vec{b} = |\vec{a}|^2 + |\vec{b}|^2 + 2\vec{a} \bullet \vec{b} \quad (3)$$

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**Good Luck !**

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**Problem 1 (2.5 points)****Answer on Scantron form**

What is the proper translation of the name Schiphol?



Figure 1: Schiphol.

1. Amsterdam Airport.
2. Cemetery of ships.
3. Hole in the dike.
4. Where a lake used to be.
5. Below sea level.
6. The best airport in the world.
7. Home of the KLM.
8. Prof. Wolfs delivered newspapers there.

**Problem 2 (2.5 points)****Answer on Scantron form**

A device consists of eight balls, each of mass  $M$ , attached to the ends of low-mass spokes of length  $L$ . The device is mounted in the vertical plane, as shown in Fig. 2. The axle is held up by supports that are not shown and the wheel is free to rotate on the nearly frictionless axle. A lump of clay with mass  $m$  falls and sticks to one of the balls at the location shown. Just before the collision, the device was rotating counter-clockwise with a constant angular velocity.

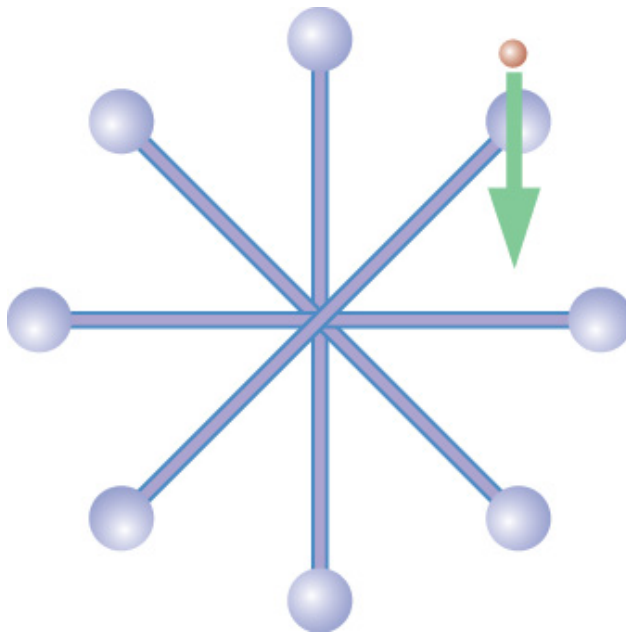


Figure 2: Rotating device colliding with a lump of clay.

Consider the following statements if the angular momentum is calculated relative to the axle of the device.

- (a) The angular momentum of the device + clay just after the collision is equal to the angular momentum of the device + clay just before the collision.
- (b) The angular momentum of the clay is zero because the clay is moving in a straight line.
- (c) Just before the collision, the angular momentum of the device is 0.
- (d) The angular momentum of the device is the sum of the angular momenta of the eight balls.
- (e) The angular momentum of the device is the same before and after the collision.

Which of the above statements are true?

1. Statements (a) and (b) are correct.

2. Statements (a) and (c) are correct.
3. Statements (a) and (d) are correct.
4. Statements (a) and (e) are correct.
5. Statements (b) and (c) are correct.
6. Statements (b) and (d) are correct.
7. Statements (b) and (e) are correct.
8. Statements (c) and (d) are correct.
9. Statements (c) and (e) are correct.
10. Statements (d) and (e) are correct.

**Problem 3 (2.5 points)****Answer on Scantron form**

A ball falls straight down in the  $xz$  plane, as shown in Fig. 3. The linear momentum of the ball is shown by the arrow.

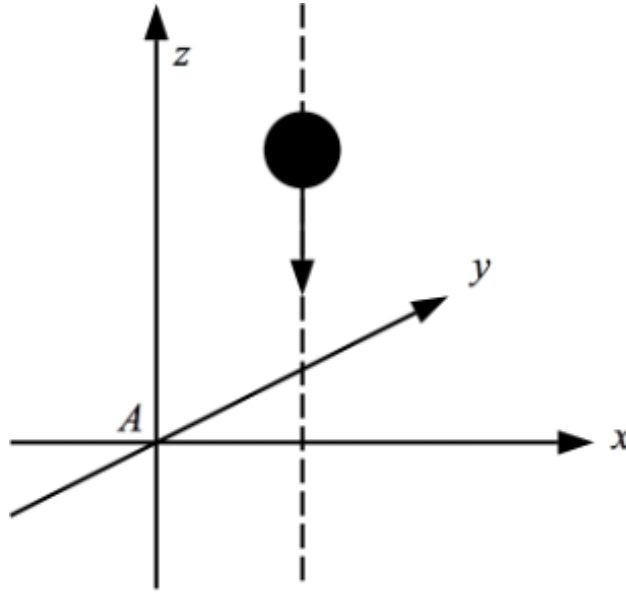


Figure 3: A ball falling in the  $xz$  plane.

What is the direction of the angular momentum of the ball about the origin of the coordinate system (point A)?

1.  $\hat{x}$
2.  $-\hat{x}$
3.  $\hat{y}$
4.  $-\hat{y}$
5.  $\hat{z}$
6.  $-\hat{z}$
7. 0

**Problem 4 (2.5 points)****Answer on Scantron form**

A diatomic molecule, such as molecular nitrogen, consists of two atoms, each of mass  $M$ , whose nuclei are a distance  $d$  apart, as shown in Fig. 4.

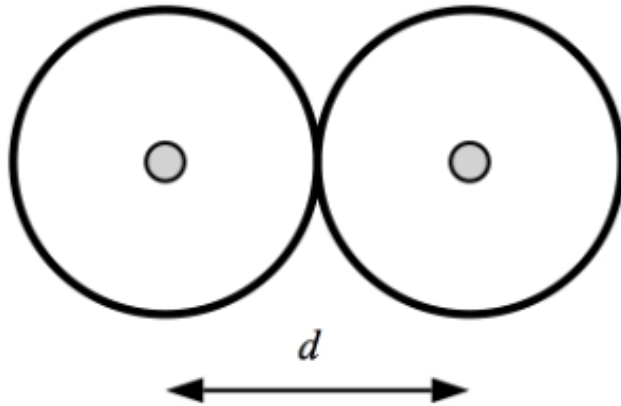


Figure 4: A diatomic molecule.

What is the moment of inertia of the molecule about its center of mass?

1.  $Md^2$ .
2.  $2Md^2$ .
3.  $4Md^2$ .
4.  $\frac{1}{2}Md^2$
5.  $\frac{1}{4}Md^2$

**Problem 5 (2.5 points)****Answer on Scantron form**

A bicycle wheel with a heavy rim is mounted on a lightweight axle, and one end of the axle rests on top of a post, as shown in Fig. 5. The wheel is observed to precess in the horizontal plane.

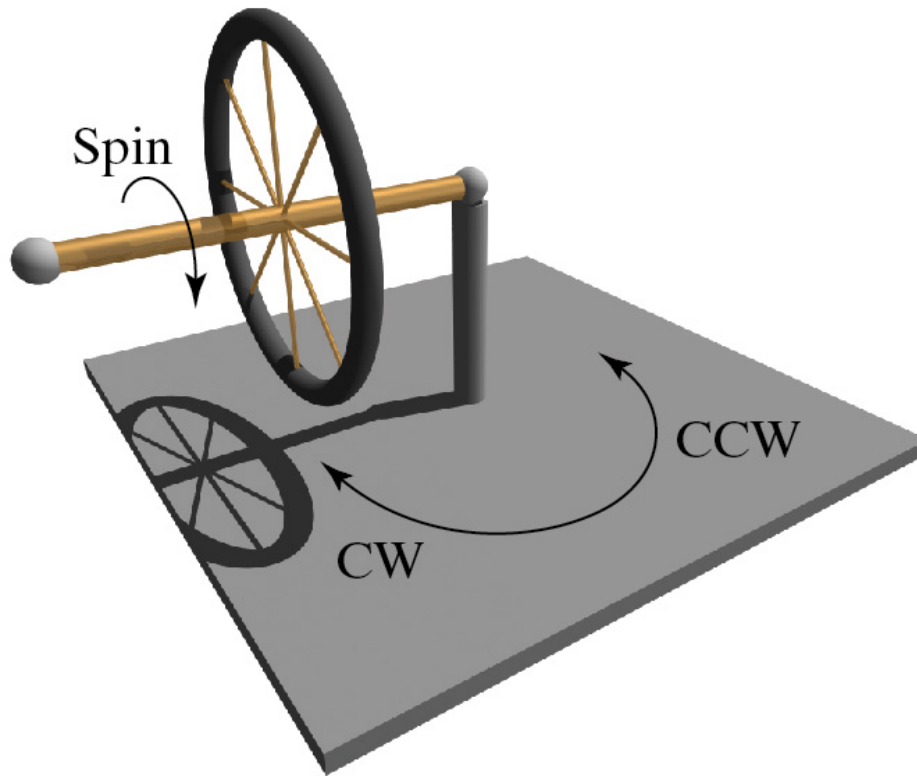


Figure 5: The path of a comet orbiting a star.

With the spin direction shown in the Fig. 5, in what direction will the wheel precess?

1. Counter clockwise.
2. Clockwise.



**Problem 6 (2.5 points)****Answer on Scantron form**

Two wheels with fixed hubs, each having a mass of 1 kg, start from rest, and two forces are applied as shown in Fig. 6. Assume the hubs and spokes are massless, so that the rotational inertia of each wheel is  $I = mR^2$ .

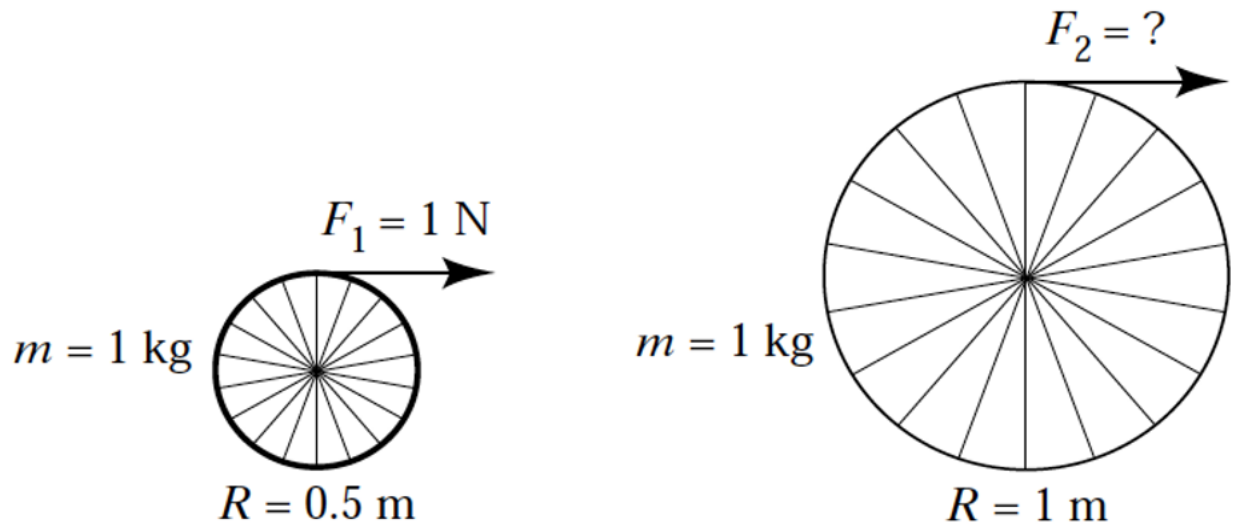


Figure 6: Two rotating wheels.

In order to impart identical angular accelerations, how large must  $F_2$  be?

1. 0.25 N
2. 0.5 N
3. 1 N
4. 2 N
5. 4 N

**Problem 7 (2.5 points)****Answer on Scantron form**

A chain of metal links is coiled up in a tight ball on a low-friction table as shown in Fig. 7. You pull on a link at one end of the chain with a constant force. Eventually the chain straightens out to its full length and you keep pulling until you have pulled your end of the chain a total distance of 4.5 m.

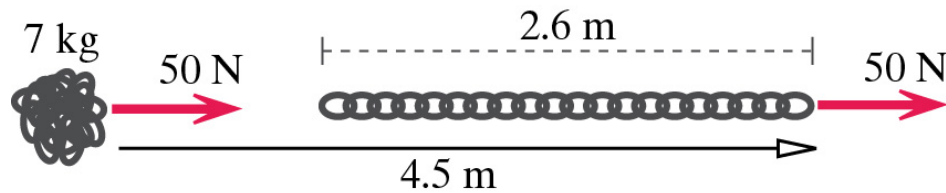


Figure 7: Pulling a chain coiled up in a tight ball.

By what distance did the center of mass of the chain move?

1. 4.5 m.
2. 7.1 m.
3. 1.9 m.
4. 3.2 m.
5. 5.8 m.

**Problem 8 (2.5 points)****Answer on Scantron form**

Which energy levels shown in Fig. 8 are appropriate for the following situations?

- (a) Nuclear states.
- (b) Electronic states of a single atom.
- (c) Hadronic states.

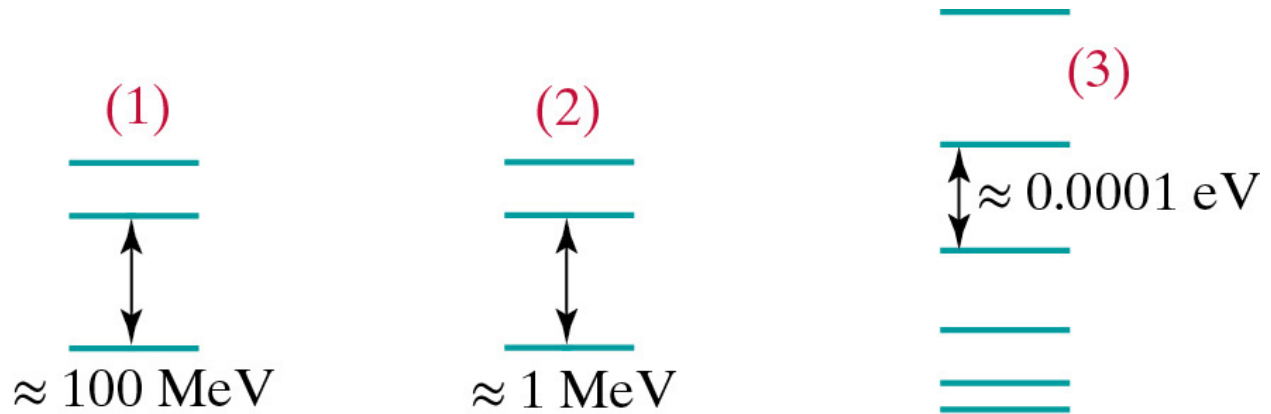


Figure 8: Energy levels.

1. (1=a), (2=b), (3=c).
2. (1=a), (2=c), (3=b).
3. (1=b), (2=a), (3=c).
4. (1=b), (2=c), (3=a).
5. (1=c), (2=a), (3=b).
6. (1=c), (2=b), (3=a).

**Problem 9 (2.5 points)****Answer on Scantron form**

Consider the energy diagram shown in Fig. 9.

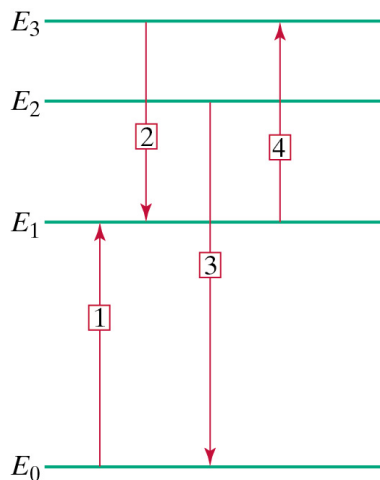


Figure 9: Atomic Transitions.

Match the description of the processes in the following list

- (a) Absorption of a photon whose energy is  $E_1 - E_0$ .
- (b) Absorption from an excited state (a rare event at low temperatures).
- (c) Emission of a photon whose energy is  $E_3 - E_1$ .
- (d) Emission of a photon whose energy is  $E_2 - E_0$ .

with the corresponding arrows in Fig. 9.

1. (1=a), (2=b), (3=c), (4=d).
2. (1=a), (2=c), (3=b), (4=d).
3. (1=a), (2=d), (3=c), (4=b).
4. (1=a), (2=c), (3=d), (4=b).
5. (1=b), (2=a), (3=c), (4=d).
6. (1=c), (2=a), (3=b), (4=d).
7. (1=c), (2=d), (3=a), (4=b).
8. (1=d), (2=c), (3=a), (4=b).
9. (1=d), (2=b), (3=c), (4=a).
10. (1=d), (2=a), (3=b), (4=c).

**Problem 10 (2.5 points)****Answer on Scantron form**

In a nuclear fission reactor, each fission of a uranium nucleus is accompanied by the emission of one or more high-speed neutrons which travel through the surrounding material. If one of these neutrons is captured by another uranium nucleus, it can trigger fission, which produces more fast neutrons, as shown schematically in Fig. 10.

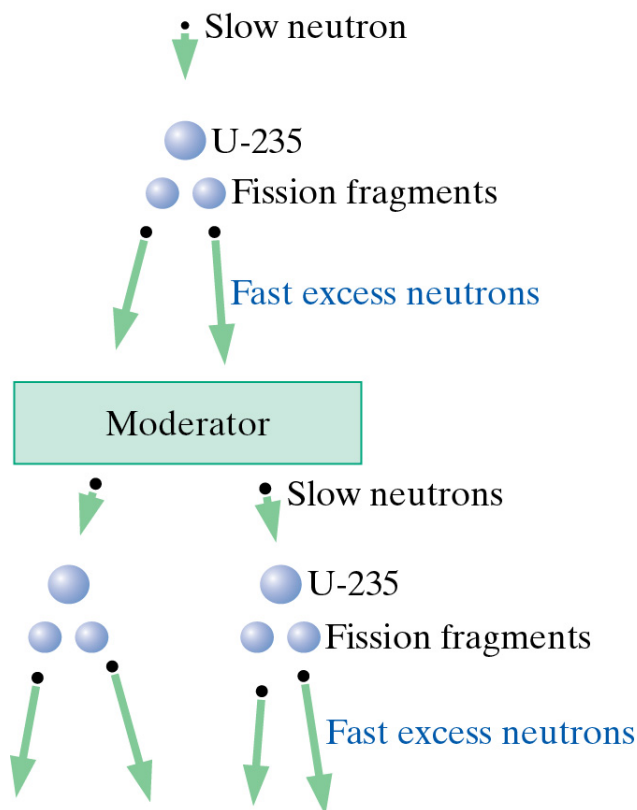


Figure 10: A chain of nuclear fission reactions.

However, fast neutrons have a low probability of capture and usually scatter off uranium nuclei without triggering fission. In order to sustain a chain reaction, the neutrons must be slowed down in some material, called a "moderator". Slow neutrons have a high probability of being captured by the uranium nuclei.

Identify the most efficient material to use as a moderator.

1.  $^{238}\text{U}$
2.  $^{208}\text{Pb}$
3.  $^{56}\text{Fe}$
4.  $^{12}\text{C}$
5.  $\text{H}_2\text{O}$

**Problem 11 (25 points)****Answer in booklet 1**

Consider an object consisting of two masses  $M$  connected by a low-mass spring with spring constant  $k$ . When you exert an upward force of  $2Mg$ , the object remains at rest, as shown in Fig. 11. In this situation, the spring is stretched by a distance  $s_i$  from its rest length. At one point, a larger constant force is applied ( $F > 2Mg$ ) and the object starts moving up. At some later time, the stretch of the spring has increased to  $s_f$ , and the object is located at the position shown in Fig. 11.

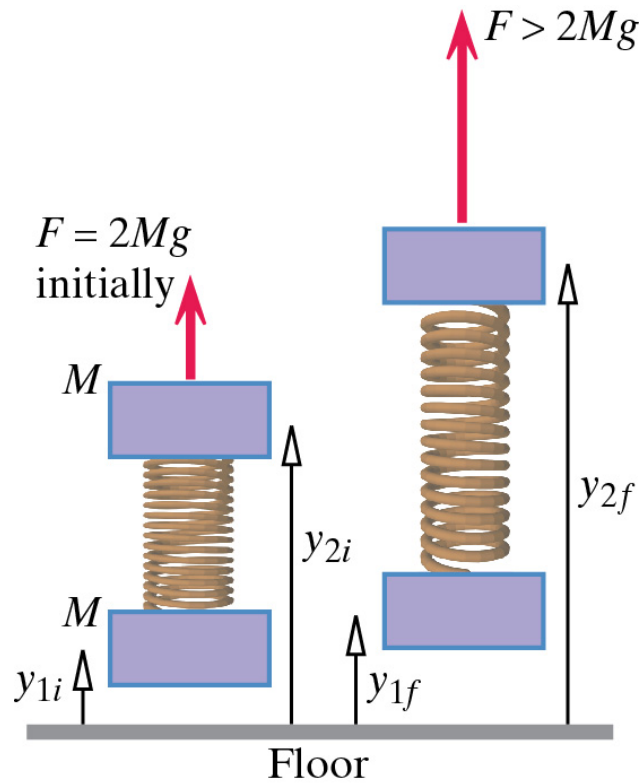


Figure 11: Motion of a mass-spring system.

- Calculate the increase in the translational kinetic energy of the two blocks.
- Calculate the vibrational kinetic energy of the two blocks.

**Your answer needs to be well motivated and expressed in terms of the variables provided.**

**Problem 12 (25 points)****Answer in booklet 1**

A yo-yo is constructed of three disks as shown in Fig. 12: two outer disks, each of mass  $M$  and radius  $R$ , and an inner disk of mass  $m$  and radius  $r$ . A string is wrapped around the inner disk. The yo-yo is suspended from the ceiling and then released.

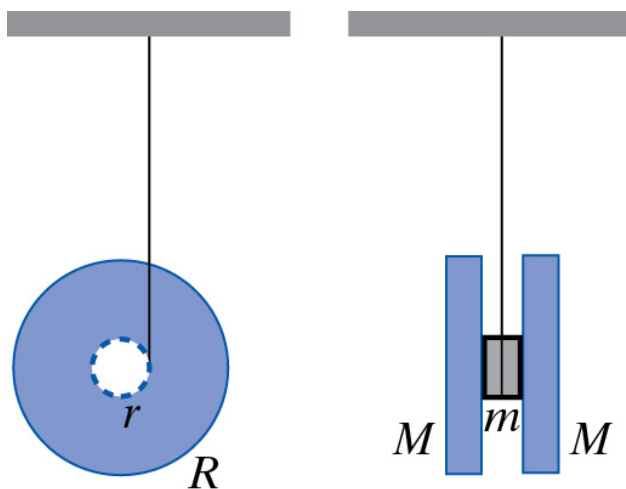


Figure 12: A yo-yo.

The purpose of this problem is to calculate the tension  $T$  in the string.

- (a) If you knew the tension  $T$ , what would be the linear acceleration of the center of mass?
- (b) If you knew the tension  $T$ , what would be the angular acceleration of the yo-yo with respect to its center of mass?
- (c) What is the relation between the linear acceleration of the center of mass and the angular acceleration of the yo-yo?
- (d) Use your answers to (a), (b), and (c) to calculate the tension  $T$ .

**Your answer needs to be well motivated and expressed in terms of the variables provided.**

**Problem 13 (25 points)****Answer in booklet 2**

Consider a two-dimensional elastic collision involving particles of equal mass  $m$  in which one of the particles is initially at rest, as shown in Fig. 13.



Figure 13: The collision system before the collision.

After the collision, the angle between the directions of these two particles is  $A$ , as shown in Fig. 14.

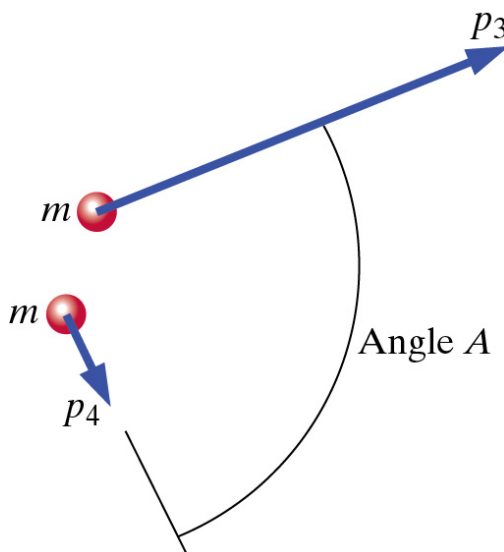


Figure 14: The collision system after the collision.

- Use vector notation to write down the relation between the initial linear momentum of the incident particle,  $\vec{p}_1$ , and the linear momenta of the two particles after the collision,  $\vec{p}_3$  and  $\vec{p}_4$ .
- Use the scalar product to obtain an expression for the magnitude of  $\vec{p}_1$  in terms of the magnitudes of  $\vec{p}_3$  and  $\vec{p}_4$  and the angle  $A$ . Note: see page 7 for details of the scalar product.
- Use the relation you derived in part (b) to obtain an expression that relates the kinetic energy of the incident particle,  $K_1$ , to the kinetic energies of the outgoing particles,  $K_3$  and  $K_4$ .
- Since the collision is elastic, what can you conclude about the angle  $A$ ?

**Your answer needs to be well motivated and expressed in terms of the variables provided.**



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Figure 15: Travel with the KLM to Indonesia in September 1929.